

BIOLOGICAL INTEGRITY
OF COTTONWOOD CREEK, FERGUS COUNTY, MONTANA
BASED ON THE COMPOSITION AND STRUCTURE
OF THE BENTHIC ALGAE COMMUNITY

Prepared for:

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SUMMARY

On August 21, 2001, periphyton samples were collected at three stations on Cottonwood Creek near Lewistown, Montana for the purpose of assessing whether the creek is water-quality limited and in need of TMDLs. The samples were collected following DEQ standard operating procedures, processed and analyzed using standard methods for periphyton, and evaluated following modified USEPA rapid bioassessment protocols for wadeable streams.

Cottonwood Creek heads in the Big Snowy Mountains but flows for most of its length through a grassland ecoregion. For this reason, Cottonwood Creek metrics were compared to biocriteria for both mountain streams and prairie streams.

Cottonwood Creek supported a diverse algal flora indicating nutrient-rich waters and a stable community with very little disturbance. The presence/absence and relative abundance of algal genera and species indicate an increase in sediment, nutrients, organics, dissolved solids, and water temperatures as one proceeds downstream.

When compared to biocriteria for mountain streams, diatom metrics at site 03 near the mouth of Cottonwood Creek indicated **partial support of aquatic life uses and moderate impairment**. The cause of this impairment was excessive siltation. However, when the diatom metrics for Cottonwood Creek were compared to criteria for *plains* streams, only minor impairment from organic loading was indicated at the downstream site. Other sites fully supported their aquatic life uses.

The presence of the cyanobacterium *Nostoc* and a very large number of diatoms in the family Epithemiaceae indicate that nitrogen was likely the limiting nutrient in Cottonwood Creek.

INTRODUCTION

This report evaluates the biological integrity, support of aquatic life uses, and probable causes of impairment to those uses, in Cottonwood Creek near Lewistown, Montana. The purpose of this report is to provide information that will help the State of Montana determine whether Cottonwood Creek is water-quality limited and in need of TMDLs.

The federal Clean Water Act directs states to develop water pollution control plans (Total Maximum Daily Loads or TMDLs) that set limits on pollution loading to water-quality limited waters. Water-quality limited waters are lakes and stream segments that do not meet water-quality standards, that is, that do not fully support their beneficial uses. The Clean Water Act and USEPA regulations require each state to (1) identify waters that are water-quality limited, (2) prioritize and target waters for TMDLs, and (3) develop TMDL plans to attain and maintain water-quality standards for all water-quality limited waters.

Evaluation of use support in this report is based on the species composition and structure of the periphyton (benthic algae, phytobenthos) community at three stream sites that were sampled on August 21, 2001. The periphyton community is a basic biological component of all aquatic ecosystems. Periphyton accounts for much of the primary production and biological diversity in Montana streams (Bahls et al. 1992).

Plafkin et al. (1989) and Stevenson and Bahls (1999) list several advantages of using periphyton in biological assessments:

- Algae are universally present in large numbers in all streams and unimpaired periphyton assemblages typically support a large number (>30) of species;
- Algae have rapid reproduction rates and short life cycles, making them useful indicators of short-term impacts;

- As primary producers, algae are most directly affected by physical and chemical factors, such as temperature, nutrients, dissolved salts, and toxins;
- Sampling is quick, easy and inexpensive, and causes minimal damage to resident biota and their habitat;
- Standard methods and criteria exist for evaluating the composition, structure, and biomass of algal associations;
- Identification to species is straightforward for the diatoms, for which there is a large body of taxonomic and ecological literature;
- Excessive algae growth in streams is often correctly perceived as a problem by the public.
- Periphyton and other biological communities reflect the *biological integrity*¹ of waterbodies; restoring and maintaining the biological integrity of waterbodies is a goal of the federal Clean Water Act;
- Periphyton and other biological communities integrate the effects of different stressors and provide a measure of their aggregate impact; and
- Periphyton and other biological communities may be the only practical means of evaluating impacts from non-point sources of pollution where specific ambient criteria do not exist (e.g., impacts that degrade habitat or increase nutrients).

Periphyton is a diverse assortment of simple photosynthetic organisms, called algae, and other microorganisms that live attached to or in close proximity of the stream bottom. Most algae, such as the diatoms, are microscopic. Diatoms are distinguished by having a cell wall composed of opaline glass--hydrated amorphous silica. Diatoms often carpet a stream bottom with a slippery brown film.

¹ *Biological integrity* is defined as "the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats within a region" (Karr and Dudley 1981).

Some algae, such as the filamentous greens, are conspicuous and their excessive growth may be aesthetically displeasing, deplete dissolved oxygen, interfere with fishing and fish spawning, clog water filters and irrigation intakes, create tastes and odors in drinking water, and cause other problems.

PROJECT AREA AND SAMPLING SITES

The project area is located in Fergus County near the city of Lewistown, Montana (pop. 6,368). Cottonwood Creek heads in the Big Snowy Mountains (maximum elevation 8,730 feet) and flows northwest for about 30 miles to where it enters Big Spring Creek near Hanover northwest of Lewistown.

Cottonwood Creek begins in the Northern Rockies Ecoregion but flows for most of its length through the Montana Valley and Foothill Prairies Ecoregion (Woods et al. 1999). All three sampling sites are within the prairie ecoregion.

The surface geology of the Cottonwood Creek watershed consists of Big Snowy dolomite and limestone in the headwaters, metamorphic rocks of the Kootenai Formation in the middle reach, and shales of the Colorado Group in the lower reach (Renfro and Feray 1972). Vegetation is alpine tundra and spruce-fir forest in the headwaters, mixed forest and grassland in the middle reach, and mixed grassland at lower elevations (USDA 1976).

Periphyton samples were collected at three sites on August 21, 2001. The upper site (M22CTWDC01) is located about 2 miles below the Cottonwood School at an elevation of 4,454 feet (Map 1). The middle site (M22CTWDC02) is located below Beaver Creek at an elevation of about 3,900 (Map 2). The lower site (M22CTWDC03) is located just above the confluence with Big Spring Creek near Hanover at an elevation of 3,700 feet (Map 2).

Coordinates of the sampling sites are as follows:

M22CTWDC01 46 57 46 N/109 29 02 W

M22CTWDC02 47 05 28 N/109 35 57 W

M22CTWDC03 47 07 34 N/109 34 18 W

Land use in the Cottonwood Creek watershed is mostly livestock and wildlife grazing and recreation. Cottonwood Creek is classified B-1 in the Montana Surface Water Quality Standards.

METHODS

Periphyton samples were collected by Rebecca Ridenour (Water Monitoring Section, MDEQ Monitoring and Data Management Bureau) following standard operating procedures of the MDEQ Planning, Prevention, and Assistance Division.

Using appropriate tools, microalgae were scraped, brushed, or sucked from natural substrates in proportion to the rank of those substrates at the study site. Macroalgae were picked by hand in proportion to their abundance at the site. All collections of microalgae and macroalgae were pooled into a common container and preserved with Lugol's solution.

The samples were examined to estimate the relative abundance and rank by biovolume of diatoms and genera of soft (non-diatom) algae according to the method described by Bahls (1993). Soft algae were identified using Dillard (1999), Prescott (1978), Smith (1950), and Whitford and Schumacher (1984). These books also served as references on the ecology of the soft algae, along with Palmer (1977).

After the identification of soft algae, the raw periphyton samples were cleaned of organic matter using sulfuric acid and

postassium dichromate, and permanent diatom slides were prepared using Naphrax, a high refractive index mounting medium, following *Standard Methods for the Examination of Water and Wastewater* (APHA 1998).

Between 428 and 454 diatom cells (856 to 908 valves) were counted at random and identified to species. The four volume series by Krammer and Lange-Bertalot (1986, 1988, 1991a, 1991b) was used as the main taxonomic and autecological reference for the diatoms. Lowe (1974), Bahls et al. (1984), van Dam et al. (1994), and Lange-Bertalot (1996) were also used as ecological references for the diatoms.

The diatom proportional counts were used to generate an array of diatom association metrics (Table 1). A metric is a characteristic of the biota that changes in some predictable way with increased human influence (Barbour et al. 1999).

Metric values from Cottonwood Creek were compared to numeric biocriteria or threshold values developed for streams in the Rocky Mountain and Great Plains Ecoregions of Montana (Tables 2 and 3). These criteria are based on metric values measured in least-impaired reference streams (Bahls et al. 1992) and on metric values measured in streams that are known to be impaired by various sources and causes of pollution (Bahls 1993).

The criteria in Tables 2 and 3 distinguish among four levels of impairment and three levels of aquatic life use support: no impairment or only minor impairment (full support); moderate impairment (partial support); and severe impairment (nonsupport). These impairment levels correspond to excellent, good, fair, and poor *biological integrity*, respectively.

Quality Assurance. Several steps were taken to assure that

the study results are accurate and reproducible.

Upon receipt of the samples, station and sample information were recorded in a laboratory notebook and the samples were assigned a unique number compatible with the Montana Diatom Database, e.g., 2196-01. The first part of this number (2196) designates the sampling site (Cottonwood Creek below Beaver Creek); the second part of this number (01) designates the number of periphyton samples that have been collected at this site to date for which data have been entered into the Montana Diatom Database.

Sample observations and analyses of soft (non-diatom) algae were recorded in a lab notebook along with station and sample information provided by MDEQ. A portion of the raw sample was used to make duplicate diatom slides. After completing the diatom proportional count, the slide used for the count will be deposited in the University of Montana Herbarium in Missoula. The other slide will be retained by *Hannaea* in Helena.

Station information, sample information, and diatom proportional count data have been entered into the Montana Diatom Database, maintained on a PC by *Hannaea* in Microsoft Access.

RESULTS AND DISCUSSION

Results are presented in Tables 4, 5, and 6, which are located near the end of this report following the References section. Spreadsheets containing completed diatom proportional counts, with species' pollution tolerance classes (PTC) and percent abundances, are attached as Appendix A.

SAMPLE NOTES

M22CTWDC01. The *Oscillatoria* in this sample comprised a large, macroscopic mat; many loose filaments were also present.

M22CTWDC02. The *Cladophora* in this sample was senescent.

NON-DIATOM ALGAE

All three sites supported a normal algal flora consisting of green algae, diatoms, and cyanobacteria (Table 4). Unattached, filamentous green algae ranked first in biovolume at all three sites: *Spirogyra* ("pond scum") at sites 01 and 02, and *Mougeotia* at site 03. A mat-forming species of *Oscillatoria* ranked second at site 01 followed by diatoms. Diatoms ranked second in biovolume at sites 02 and 03, where another filamentous green--*Oedogonium*--ranked third.

An abundance of unattached filamentous greens in Cottonwood Creek is an indication of slower current velocities and elevated nutrient concentrations. *Audouinella*, a red alga that prefers cool waters and lower levels of nutrients, was common at site 01, occasional at site 02, and absent at site 03 (Table 4). *Nostoc*, a nitrogen-fixer that also prefers low nutrient levels and cool water temperatures, was present at site 01 but absent from the other two sites.

The appearance of *Euglena* at site 03 (Table 4) may signal an increase in organic loading at this site. *Euglena* is very tolerant of decomposing organic matter. The appearance of *Merismopedia* and *Rivularia* at site 03 indicates an increase in dissolved solids here. *Anabaena*, which prefers warmer waters, was absent from site 01, occasional at site 02, and frequent at site 03, indicating an increase in water temperatures downstream. However, *Tribonema*, which is a cool water genus, was also present at site 03.

DIATOMS

All of the major diatom species in Cottonwood Creek are either tolerant of a wide range of trophic conditions--from oligotrophic to eutrophic--or produce their largest populations only in stronger mesotrophic to eutrophic waters (Tables 5 and 6). Two of these major species--*Cocconeis pediculus* and *Epithemia sorex*--are epiphytes with one concave valve surface that is so adapted to living attached to filaments of green algae.

All three sites on Cottonwood Creek had excellent diatom diversity, species richness, and equitability (Table 5 and 6). The disturbance index (% *Achnanthes minutissimum*) was low at all sites, indicating very little chemical, physical, or biological disturbance and high community stability.

The pollution index indicated minor impairment but full support of aquatic life uses at all three sites when compared to biocriteria for mountain streams in Table 2 (Table 5). When compared to criteria for plains streams in Table 3, the pollution index indicated minor impairment only at site 03, and no impairment at sites 01 and 02 (Table 6).

The siltation index indicated minor impairment at sites 01 and 02, and moderate impairment with partial support of aquatic life uses at site 03 when judged against biocriteria for mountain streams in Table 2 (see Table 5). The siltation index increased in a downstream direction. When compared to the criteria for plains streams, the siltation index indicated no impairment and full support of aquatic life uses at all three sites (Table 6).

The siltation index is the percentage of diatoms in the genera *Navicula*, *Nitzschia*, and *Surirella*. Diatoms in these

genera are motile and capable of maintaining their position on top of aggrading substrates.

A small number of teratological cells was counted at sites 02 and 03, indicating minor impairment of aquatic life uses. Salinity, heavy metals, and organic loading are three of several factors that have been shown to cause diatom deformities.

No diatoms in the family Epithemiaceae were counted at site 01 (Tables 5 and 6). On the other hand, exceptionally large numbers of diatoms in this family were recorded at sites 02 and 03. Diatoms in the family Epithemiaceae harbor nitrogen-fixing cyanobacteria within their cells. Hence, the large number of diatoms in this family indicate that nitrogen is likely the limiting nutrient at sites 02 and 03.

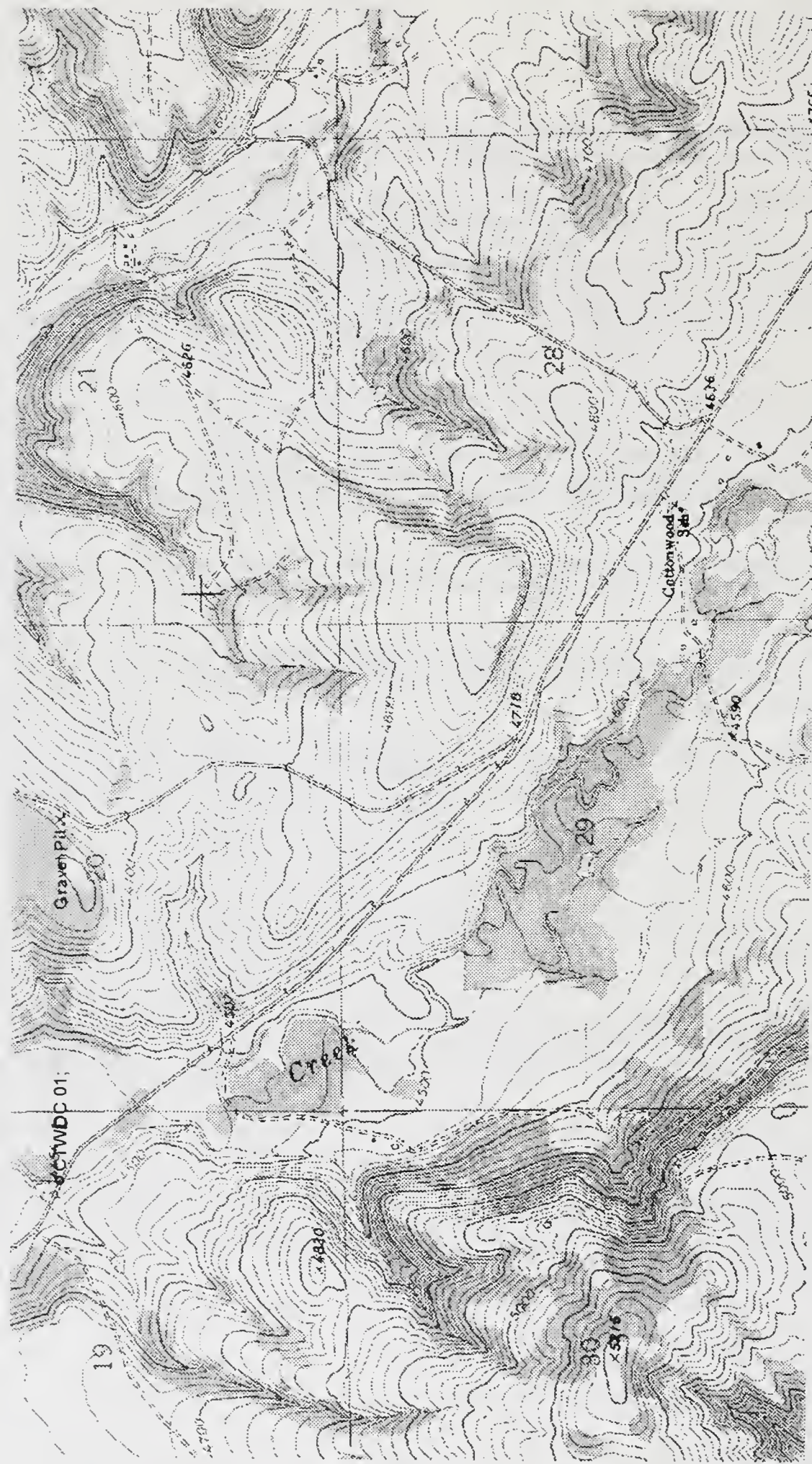
Adjacent sites on Cottonwood Creek shared between 40% and 50% of their diatom floras (Similarity Index, Tables 5 and 6). This level of similarity indicates only minor change in environmental conditions between adjacent sites.

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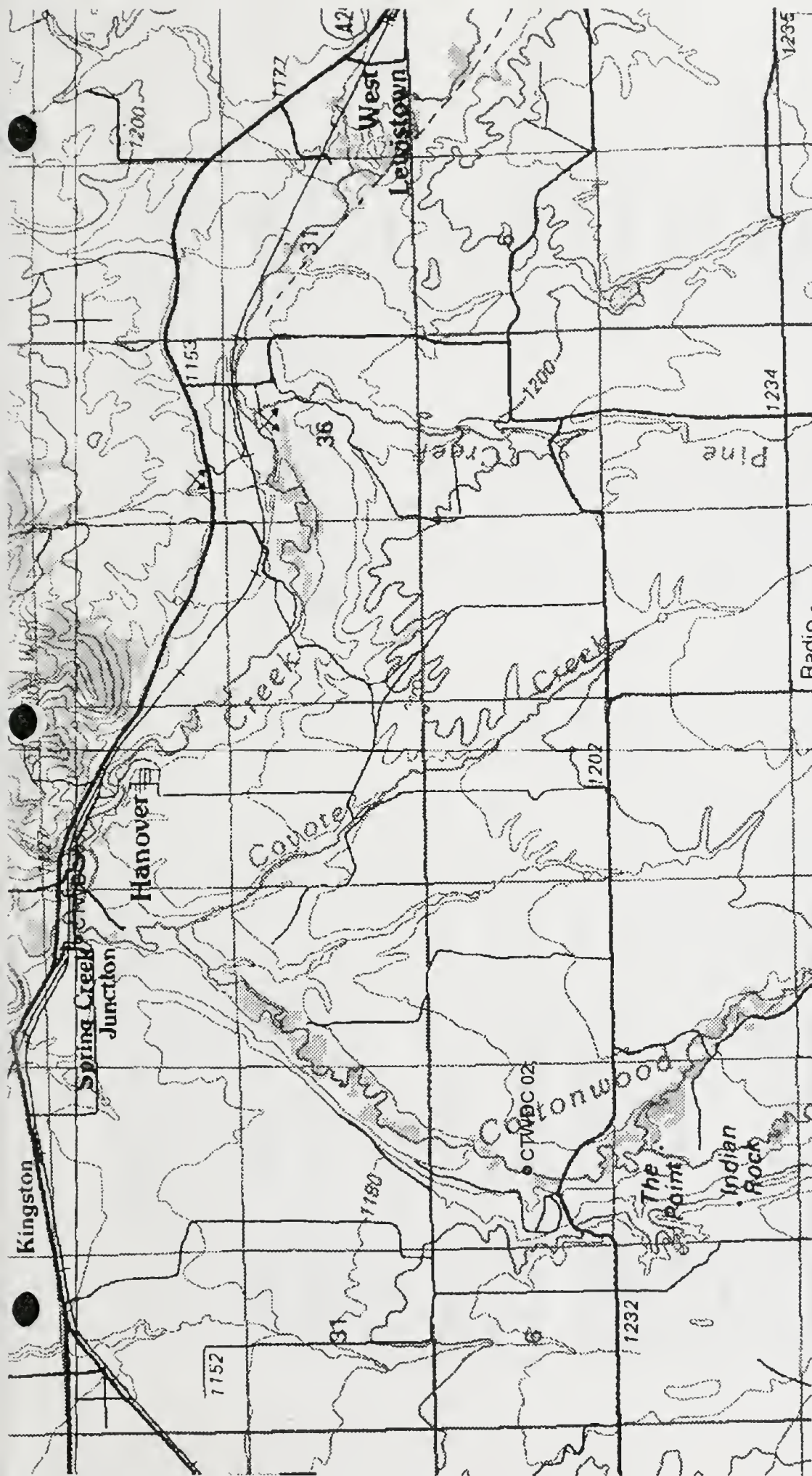
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Map 1. Cottonwood Creek Station 01 (M22CTWDC01).



Map 2. Cottonwood Creek Stations 02 and 03 (M22CTWDC02, 03).

Table 1. Diatom association metrics used to evaluate biological integrity in Montana streams: reference, range of values in Montana streams, and expected direction of metric response to increasing anthropogenic perturbation or natural stress.

Metric	Reference	Range of Values	Expected Response
Shannon Species Diversity	Bahls 1979	0.00-5.00+	Decrease ¹
Pollution Index ²	Bahls 1993	1.00-3.00	Decrease
Siltation Index ³	Bahls 1993	0.00-90.0+	Increase
Disturbance Index ⁴	Barbour et al. 1999	0.00-100.0	Increase
No. Species Counted	Bahls 1979, 1993	0-100+	Decrease ¹
Percent Dominant Species	Barbour et al. 1999	5.0-100.0	Increase
Percent Abnormal Cells	McFarland et al. 1997	0.0-20.0+	Increase
Similarity Index	Whittaker 1952	0.0-80.0+	Decrease
Percent Epithemiaceae	Stevenson & Pan 1999	0.0-80.0+	Decrease
Percent Aerophiles	Johansen 1999	0.0-100	Increase

¹ Shannon diversity and species richness may increase somewhat in naturally nutrient-poor mountain streams in response to slight to moderate increases in nutrients or sediment.

² Composite numeric expression of the pollution tolerances assigned by Lange-Bertalot (1979) to the common diatom species.

³ Sum of the percent abundances of all species in the genera *Navicula*, *Nitzschia*, and *Surirella*.

⁴ Percent abundance of *Achnanthes minutissima*.

Table 2. Criteria for rating levels of biological integrity, environmental impairment or natural stress, and aquatic life use support in wadeable **mountain** streams of Montana using selected metrics for benthic diatom associations. The lowest rating for any one metric is the overall rating for the study site.

Biological Integrity/ Impairment or Natural Stress/Use Support	Diversity Index (Shannon)	Pollution Index	Siltation Index	Disturbance Index	Number of Species Counted	Percent Dominant Species	Percent Abnormal Cells	Percent Similarity Index ¹
Excellent None/Full Support	>2.99	>2.50	<20.0	<25.0	>29	<25.0	0.0	>59.9
Good/Minor Full Support	2.00- 2.99	2.01- 2.50	20.0- 39.9	25.0- 49.9	20- 29	25.0- 49.9	>0.0- <1.0	40.0- 59.9
Fair/Moderate Partial Support	1.00- 1.99	1.50- 2.00	40.0- 59.9	50.0- 74.9	10- 19	50.0- 74.9	1.0- 9.9	20.0- 39.9
Poor/Severe Nonsupport	<1.00	<1.50	>59.9	>74.9	<10	>74.9	>9.9	<20.0

¹ The Similarity Index or Percent Community Similarity (Whittaker 1952) may be used to compare a study site to an unimpaired upstream control site on the same stream. This metric measures the degree of floristic similarity between diatom associations at the two sites and is the sum of the smaller of the two percent abundance values for each species that is common to both sites. Adjacent riffles on the same stream, without intervening tributaries or environmental perturbations, will generally have at least 60% of their diatom floras in common (Bahls 1993). PCS may also be used to gauge the relative amount of impairment or recovery that occurs between adjacent study sites: >59.9% = very similar floras, no change; 40.0-59.9% = somewhat similar floras, minor change; 20.0-39.9% = somewhat dissimilar floras, moderate change; <20.0% = very dissimilar floras, major change.

Table 3. Criteria for rating levels of biological integrity, environmental impairment or natural stress, and aquatic life use support in wadeable **plains** streams of Montana using selected metrics for benthic diatom associations. The lowest rating for any one metric is the overall rating for the study site.

Biological Integrity/ Impairment or Natural Stress/Use Support	Diversity Index (Shannon)	Pollution Index	Siltation Index	Disturbance Index	Number of Species Counted	Percent Dominant Species	Percent Abnormal Cells	Percent Similarity Index ¹
Excellent None/Full Support	>3.99	>2.25	<50.0	<25.0	>39	<25.0	0.0	>59.9
Good/Minor Full Support	3.00- 3.99	1.76- 2.25	50.0- 69.9	25.0- 49.9	30- 39	25.0 49.9	>0.0- <1.0	40.0- 59.9
Fair/Moderate Partial Support	2.00- 2.99	1.25- 1.75	70.0- 89.9	50.0- 74.9	20- 29	50.0- 74.9	1.0- 9.9	20.0- 39.9
Poor/Severe Nonsupport	<2.00	<1.25	>89.9	>74.9	<20	>74.9	>9.9	<20.0

¹ The Similarity Index or Percent Community Similarity (Whittaker 1952) may be used to compare a study site to an unimpaired upstream control site on the same stream. This metric measures the degree of floristic similarity between diatom associations at the two sites and is the sum of the smaller of the two percent abundance values for each species that is common to both sites. Adjacent riffles on the same stream, without intervening tributaries or environmental perturbations, will generally have at least 60% of their diatom floras in common (Bahls 1993). PCS may also be used to gauge the relative amount of impairment or recovery that occurs between adjacent study sites: >59.9% = very similar floras, no change; 40.0-59.9% = somewhat similar floras, minor change; 20.0-39.9% = somewhat dissimilar floras, moderate change; <20.0% = very dissimilar floras, major change.

Table 4. Relative abundance of cells and rank by biovolume of diatoms and genera of non-diatom algae in periphyton samples collected from Cottonwood Creek on 8/21/01: d = dominant; a = abundant; f = frequent; c = common; o = occasional; r = rare.

Taxa	Relative Abundance and Rank		
	M22CTWDC01	M22CTWDC02	M22CTWDC03
Chlorophyta (green algae)			
<i>Ankistrodesmus</i>	o		c
<i>Cladophora</i>		c/4	
<i>Closterium</i>	r	o	r
<i>Cosmarium</i>	c/5		o
<i>Mougeotia</i>		o/5	d/1
<i>Oedogonium</i>		f/3	f/3
<i>Oocystis</i>			r
<i>Pediastrum</i>		r	r
<i>Rhizoclonium</i>			o/7
<i>Scenedesmus</i>		o	o
<i>Spirogyra</i>	a/1	a/1	f/4
<i>Zygnema</i>			c/8
Euglenophyta (euglenoid algae)			
<i>Euglena</i>			r
Chrysophyta (golden algae)			
Diatoms	a/3	a/2	a/2
<i>Tribonema</i>			o
Rhodophyta (red algae)			
<i>Audouinella</i>	c/4	o	
Cyanophyta (cyanobacteria) ¹			
<i>Amphithrix</i>	o/6		
<i>Anabaena</i>		o	f/5
<i>Calothrix</i>	r	r	o
<i>Lyngbya</i>			f/6
<i>Merismopedia</i>			o
<i>Nostoc</i>	o		
<i>Oscillatoria</i>	a/2		o
<i>Phormidium</i>	o	o	o
<i>Rivularia</i>			o/9

¹ Formerly known as blue-green algae

Table 5. Percent abundance of major diatom species¹ and values of selected diatom association metrics for periphyton samples collected from Cottonwood Creek on 8/21/01. Underlined values indicate good biological integrity, minor impairment, and full support of aquatic life uses; **bold values** indicate fair biological integrity, moderate impairment, and partial support of aquatic life uses; all other values indicate excellent biological integrity, no impairment, and full support of aquatic life uses when compared to criteria for **mountain** streams in Table 2.

Species/Metric (Autecology) ²	<u>Percent Abundance/Metric Values</u>		
	M22CTWDC01	M22CTWDC02	M22CTWDC03
<i>Achnantheidium minutissimum</i> (tol)	12.67	7.15	4.55
<i>Cocconeis pediculus</i> (eu)		6.82	3.50
<i>Cymbella affinis</i> (eu)	8.45	3.41	0.23
<i>Encyonopsis microcephala</i> (tol)	9.59	0.22	0.00
<i>Epithemia sorex</i> (eu)		17.60	14.57
<i>Gomphonema parvulum</i> (tol)	3.20	5.28	1.98
<i>Navicula capitatoradiata</i> (eu)	3.20	1.54	5.83
<i>Navicula cryptotenella</i> (tol)	5.02	2.75	
<i>Nitzschia frustulum</i> (eu)		8.25	5.13
<i>Nitzschia palea</i> (eu)	4.34	5.06	11.07
<i>Nitzschia paleacea</i> (eu)	0.46	1.10	6.99
<i>Synedra ulna</i> (eu)	12.33	4.51	12.94
Cells Counted	438	454	428
Total Species	60	75	68
Species Counted	59	61	59
Species Diversity	4.60	4.73	4.52
Percent Dominant Species	12.67	17.60	14.57
Disturbance Index	12.67	7.15	4.55
Pollution Index	<u>2.34</u>	<u>2.40</u>	<u>2.15</u>
Siltation Index	<u>26.60</u>	<u>36.52</u>	<u>43.17</u>
Percent Abnormal Cells	0.00	<u>0.22</u>	<u>0.12</u>
Percent Epithemiaceae	0.00	18.37	20.63
Similarity Index ³		43.67	48.56

¹ A major diatom species is one that accounts for 3% or more of the cells in one or more samples of a sample set

² Autecology

eu: best growth in stronger mesotrophic to eutrophic waters

tol: tolerant of a wide range of trophic status from oligo- to eutrophic waters without discernible preference

³ The percent community similarity between CTWDC 01 and CTWDC 03 was 38.04%.

Table 6. Percent abundance of major diatom species¹ and values of selected diatom association metrics for periphyton samples collected from Cottonwood Creek on 8/21/01. Underlined values indicate good biological integrity, minor impairment, and full support of aquatic life uses; all other values indicate excellent biological integrity, no impairment, and full support of aquatic life uses when compared to criteria for prairie streams in Table 3.

Species/Metric (Autecology) ²	Percent Abundance/Metric Values		
	M22CTWDC01	M22CTWDC02	M22CTWDC03
<i>Achnanthes minutissimum</i> (tol)	12.67	7.15	4.55
<i>Cocconeis pediculus</i> (eu)		6.82	3.50
<i>Cymbella affinis</i> (eu)	8.45	3.41	0.23
<i>Encyonopsis microcephala</i> (tol)	9.59	0.22	0.00
<i>Epithemia sorex</i> (eu)		17.60	14.57
<i>Gomphonema parvulum</i> (tol)	3.20	5.28	1.98
<i>Navicula capitatoradiata</i> (eu)	3.20	1.54	5.83
<i>Navicula cryptotenella</i> (tol)	5.02	2.75	
<i>Nitzschia frustulum</i> (eu)		8.25	5.13
<i>Nitzschia palea</i> (eu)	4.34	5.06	11.07
<i>Nitzschia paleacea</i> (eu)	0.46	1.10	6.99
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Siltation Index	26.60	36.52	43.17
Percent Abnormal Cells	0.00	<u>0.22</u>	<u>0.12</u>
Percent Epithemiaceae	0.00	18.37	20.63
Similarity Index ³		43.67	48.56

¹ A major diatom species is one that accounts for 3% or more of the cells in one or more samples of a sample set

² Autecology

eu: best growth in stronger mesotrophic to eutrophic waters

tol: tolerant of a wide range of trophic status from oligo- to eutrophic waters without discernible preference

³ The percent community similarity between CTWDC 01 and CTWDC 03 was 38.04%.

APPENDIX A: DIATOM PROPORTIONAL COUNTS

Sample	Genus/Species/Variety	Pollution Tolerance Class	Count	Percent
219501	Achnanthes lanceolata	2	2	0.23
219501	Achnanthes sp.	3	2	0.23
219501	Achnanthidium affine	3	2	0.23
219501	Achnanthidium biasolettianum	3	20	2.28
219501	Achnanthidium minutissimum	3	111	12.67
219501	Amphipleura pellucida	2	34	3.88
219501	Amphora libyca	3	3	0.34
219501	Aulacoseira distans	3	2	0.23
219501	Aulacoseira islandica	3	2	0.23
219501	Caloneis bacillum	2	0	0.00
219501	Cocconeis placentula	3	10	1.14
219501	Cyclotella meneghiniana	2	1	0.11
219501	Cymbella affinis	3	74	8.45
219501	Cymbella hebridica	3	1	0.11
219501	Cymbella mexicana	3	1	0.11
219501	Cymbella sp.	3	1	0.11
219501	Diatoma moniliformis	2	34	3.88
219501	Diploneis oblongella	3	4	0.46
219501	Encyonema brehmii	2	27	3.08
219501	Encyonema silesiacum	2	3	0.34
219501	Encyonopsis cesatii	3	2	0.23
219501	Encyonopsis microcephala	2	84	9.59
219501	Fragilaria capucina	2	3	0.34
219501	Fragilaria vaucheriae	2	3	0.34
219501	Gomphonema angustatum	2	4	0.46
219501	Gomphonema minutum	3	35	4.00
219501	Gomphonema olivaceum	3	4	0.46
219501	Gomphonema parvulum	1	28	3.20
219501	Gomphonema pumilum	3	17	1.94
219501	Navicula capitatoradiata	2	28	3.20
219501	Navicula cryptocephala	3	8	0.91
219501	Navicula cryptotenella	2	44	5.02
219501	Navicula radiosa	3	3	0.34
219501	Navicula reichardtiana	2	11	1.26
219501	Navicula stroemii	2	4	0.46
219501	Navicula tripunctata	3	5	0.57
219501	Navicula trivialis	2	2	0.23
219501	Navicula veneta	1	2	0.23
219501	Navicula viridula	2	1	0.11
219501	Nitzschia acicularis	2	4	0.46
219501	Nitzschia angustata	2	3	0.34
219501	Nitzschia angustatula	2	2	0.23
219501	Nitzschia apiculata	2	2	0.23
219501	Nitzschia dissipata	3	35	4.00
219501	Nitzschia fonticola	3	6	0.68
219501	Nitzschia incognita	2	8	0.91
219501	Nitzschia linearis	2	14	1.60
219501	Nitzschia palea	1	38	4.34
219501	Nitzschia paleacea	2	4	0.46
219501	Nitzschia pusilla	1	2	0.23
219501	Nitzschia recta	3	1	0.11
219501	Nitzschia sociabilis	2	2	0.23
219501	Nitzschia supralitoria	2	2	0.23
219501	Reimeria sinuata	3	1	0.11
219501	Stauroneis smithii	2	4	0.46
219501	Staurosira construens	3	6	0.68
219501	Staurosirella pinnata	3	6	0.68
219501	Synedra rumpens	2	4	0.46
219501	Synedra ulna	2	108	12.33

Sample	Genus/Species/Variety	Pollution Tolerance Class	Count	Percent
219601	Achnanthes lanceolata	2	3	0.33
219601	Achnanthidium minutissimum	3	65	7.15
219601	Amphipleura pellucida	2	1	0.11
219601	Amphora inariensis	3	1	0.11
219601	Amphora libyca	3	1	0.11
219601	Amphora pediculus	3	12	1.32
219601	Aulacoseira distans	3	3	0.33
219601	Aulacoseira islandica	3	2	0.22
219601	Caloneis bacillum	2	5	0.55
219601	Caloneis silicula	2	2	0.22
219601	Cocconeis pediculus	3	62	6.82
219601	Cocconeis placentula	3	37	4.07
219601	Cyclotella meneghiniana	2	9	0.99
219601	Cylindrotheca gracilis	2	0	0.00
219601	Cymbella affinis	3	31	3.41
219601	Diatoma moniliformis	2	10	1.10
219601	Diatoma vulgare	3	1	0.11
219601	Diploneis oblongella	3	0	0.00
219601	Diploneis parva	3	2	0.22
219601	Encyonema auerswaldii	2	0	0.00
219601	Encyonema brehmii	2	0	0.00
219601	Encyonema silesiacum	2	5	0.55
219601	Encyonopsis microcephala	2	2	0.22
219601	Epithemia sorex	3	160	17.60
219601	Epithemia turgida	3	0	0.00
219601	Gomphonema minutum	3	23	2.53
219601	Gomphonema parvulum	1	48	5.28
219601	Gomphonema pumilum	3	2	0.22
219601	Gomphonema truncatum	3	2	0.22
219601	Gyrosigma acuminatum	3	1	0.11
219601	Navicula acceptata	2	0	0.00
219601	Navicula capitatoradiata	2	14	1.54
219601	Navicula cari	2	2	0.22
219601	Navicula cryptotenella	2	25	2.75
219601	Navicula elginensis	3	0	0.00
219601	Navicula gregaria	2	2	0.22
219601	Navicula lenzii	2	12	1.32
219601	Navicula menisculus	2	0	0.00
219601	Navicula minima	1	2	0.22
219601	Navicula peregrina	2	1	0.11
219601	Navicula pupula	2	7	0.77
219601	Navicula pygmaea	2	0	0.00
219601	Navicula reichardtiana	2	12	1.32
219601	Navicula tripunctata	3	8	0.88
219601	Navicula trivialis	2	4	0.44
219601	Navicula viridula	2	0	0.00
219601	Nitzschia acicularis	2	16	1.76

Sample	Genus/Species/Variety	Pollution Tolerance Class	Count	Percent
219601	Nitzschia amphibia	2	0	0.00
219601	Nitzschia angustata	2	3	0.33
219601	Nitzschia angustatula	2	2	0.22
219601	Nitzschia capitellata	2	2	0.22
219601	Nitzschia dissipata	3	36	3.96
219601	Nitzschia frustulum	2	75	8.25
219601	Nitzschia gracilis	2	8	0.88
219601	Nitzschia heufleriana	3	3	0.33
219601	Nitzschia incognita	2	15	1.65
219601	Nitzschia liebetruthii	2	0	0.00
219601	Nitzschia linearis	2	0	0.00
219601	Nitzschia palea	1	46	5.06
219601	Nitzschia paleacea	2	10	1.10
219601	Nitzschia pusilla	1	1	0.11
219601	Nitzschia sociabilis	2	5	0.55
219601	Nitzschia solita	1	8	0.88
219601	Nitzschia vermicularis	2	11	1.21
219601	Reimeria sinuata	3	4	0.44
219601	Rhoicosphenia curvata	3	0	0.00
219601	Rhopalodia gibba	2	6	0.66
219601	Rhopalodia operculata	1	1	0.11
219601	Simonsenia delognei	2	2	0.22
219601	Staurosira construens	3	10	1.10
219601	Stephanodiscus hantzschii	2	6	0.66
219601	Surirella minuta	2	2	0.22
219601	Synedra acus	2	10	1.10
219601	Synedra rumpens	2	7	0.77
219601	Synedra ulna	2	41	4.51

Sample	Genus/Species/Variety	Pollution Tolerance Class	Count	Percent
219701	Achnanthes lanceolata	2	1	0.12
219701	Achnanthidium minutissimum	3	39	4.55
219701	Amphora libyca	3	2	0.23
219701	Amphora pediculus	3	7	0.82
219701	Cocconeis pediculus	3	30	3.50
219701	Cocconeis placentula	3	11	1.28
219701	Cyclotella meneghiniana	2	9	1.05
219701	Cymatopleura solea	2	0	0.00
219701	Cymbella affinis	3	2	0.23
219701	Cymbella cistula	3	0	0.00
219701	Diatoma moniliformis	2	1	0.12
219701	Encyonema silesiacum	2	1	0.12
219701	Encyonopsis microcephala	2	0	0.00
219701	Epithemia adnata	2	3	0.35
219701	Epithemia sores	3	125	14.57
219701	Epithemia turgida	3	4	0.47
219701	Fragilaria capucina	2	12	1.40
219701	Fragilaria vaucheriae	2	1	0.12
219701	Gomphonema minutum	3	12	1.40
219701	Gomphonema parvulum	1	17	1.98
219701	Melosira varians	2	7	0.82
219701	Navicula acceptata	2	2	0.23
219701	Navicula bryophila	3	2	0.23
219701	Navicula capitatoradiata	2	50	5.83
219701	Navicula clementioides	3	0	0.00
219701	Navicula kotschy	2	1	0.12
219701	Navicula menisculus	2	5	0.58
219701	Navicula minima	1	2	0.23
219701	Navicula omissa	1	2	0.23
219701	Navicula pupula	2	1	0.12
219701	Navicula radiosa	3	0	0.00
219701	Navicula recens	2	1	0.12
219701	Navicula reichardtiana	2	17	1.98
219701	Navicula trivialis	2	2	0.23
219701	Navicula veneta	1	8	0.93
219701	Nitzschia acicularis	2	6	0.70
219701	Nitzschia agnita	1	16	1.86
219701	Nitzschia amphibia	2	5	0.58
219701	Nitzschia angustata	2	0	0.00
219701	Nitzschia angustatula	2	0	0.00
219701	Nitzschia apiculata	2	3	0.35
219701	Nitzschia communis	1	0	0.00
219701	Nitzschia dissipata	3	19	2.21
219701	Nitzschia frustulum	2	44	5.13
219701	Nitzschia gracilis	2	4	0.47
219701	Nitzschia incognita	2	9	1.05
219701	Nitzschia linearis	2	5	0.58

Sample	Genus/Species/Variety	Pollution Tolerance Class	Count	Percent
219701	Nitzschia palea	1	95	11.07
219701	Nitzschia paleacea	2	60	6.99
219701	Nitzschia recta	3	1	0.12
219701	Nitzschia sigmoidea	3	0	0.00
219701	Nitzschia sociabilis	2	2	0.23
219701	Nitzschia solita	1	6	0.70
219701	Nitzschia vermicularis	2	2	0.23
219701	Pleurosigma delicatulum	2	1	0.12
219701	Reimeria sinuata	3	15	1.75
219701	Rhoicosphenia curvata	3	4	0.47
219701	Rhopalodia brebissonii	1	2	0.23
219701	Rhopalodia gibba	2	42	4.90
219701	Rhopalodia operculata	1	1	0.12
219701	Simonsenia delognei	2	3	0.35
219701	Stauroneis smithii	2	2	0.23
219701	Staurosirella pinnata	3	4	0.47
219701	Stephanodiscus hantzschii	2	1	0.12
219701	Synedra acus	2	14	1.63
219701	Synedra famelica	2	2	0.23
219701	Synedra filiformis	3	2	0.23
219701	Synedra ulna	2	111	12.94

